

Therefore, the oxygen activity depends greatly on the amount of hydrogen present. Note also that the mole fraction of hydrogen cannot be zero, because of the dissociation of steam. Under these circumstances, the oxygen activity is described by the following equation.

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$$a_{O_2} = \left( \frac{(1 - X_{H_2})}{X_{H_2}} \cdot \frac{1}{K_2} \right)^2 \quad (16)$$

The activity of nickel oxide was calculated from equations (16) and (10) for steam purge gas mixtures having 0.10% - 2.00% hydrogen, at temperatures in the range of 400 °C to 900 °C. The results are illustrated in Figure 2, which is a plot of the calculated activity of NiO in the presence of the different purge gas mixtures within the specified temperature range.

As indicated in Figure 2, the oxidation of nickel catalyst during purging of a steam reformer is likely to occur unless greater than 0.25% hydrogen is added to the steam. Oxidation of the catalyst is likely prevented at temperatures above 650 °C when 0.50% hydrogen is added. Steam purge gas comprising 1% or more hydrogen may prevent oxidation of the catalyst over the entire temperature range.

In another embodiment of the present method, the purge gas supplied to the steam reformer comprises steam and greater than 0.25% hydrogen by volume. For example, the purge gas may have greater than 0.25% to about 2% hydrogen by volume. As another example, the purge gas may have at least 0.5% hydrogen by volume, and may have between about 0.5% and about 1% hydrogen by volume.

Where the purge gas comprises steam, conditions in the reformer should be controlled so as to avoid condensation of the steam onto the catalyst. Condensation is to be avoided as it can result in physical damage to the catalyst.

In another embodiment, the present method comprises supplying a purge gas comprising steam and hydrogen to the steam reformer, and maintaining the catalyst at a temperature above the condensation temperature of purge gas. In another embodiment of

the present fuel processing system, the system further comprises means for maintaining the catalyst at a temperature above the condensation temperature of the purge gas. Suitable such means include, but are not limited to, resistive heating elements, heat exchangers, and burners. For example, the reformer catalyst bed may have resistive heating elements  
5 associated therewith for heating the bed. As another example, heat exchangers, such as coils or plates, could be employed. As a further example, in shell-and-tube steam reformer designs, for example, a burner may be employed to heat the tube(s) containing the catalyst. Other equivalent direct and indirect heating apparatus will be apparent to persons skilled in the art. The selection of particular means for maintaining the catalyst bed at a suitable  
10 temperature is not essential to the present method or fuel processing system, and persons skilled in the art can select suitable such means for a given application.

In another embodiment, the method further comprises adding another inert gas, such as nitrogen, to the purge gas. For example, the steam purge described in the preceding embodiment could be followed by a purge with nitrogen and hydrogen. As  
15 steam is removed from the reformer, the temperature of the catalyst bed could be reduced without the risk of condensation. This, in turn, may reduce the costs associated with maintaining the catalyst bed at a temperature above the condensation temperature of the purge gas. Alternatively, the reformer could be supplied with a purge gas comprising a mixture of steam, nitrogen (or other inert gas, such as argon, or carbon dioxide, for  
20 example) and hydrogen. Since the condensation temperature of the purge gas is determined by the partial pressure of steam, the addition of nitrogen will decrease the condensation temperature of the purge gas and may reduce the costs associated with maintaining the catalyst bed at a suitable temperature. At the same time, because nitrogen makes up only a portion of the purge gas, the size of the nitrogen supply for the fuel processing system may  
25 be reduced and/or the replacement interval may be increased, thus saving costs. As a further alternative, the amount of steam and dry inert gas may be varied over time to reduce the partial pressure of steam in the purge gas, thereby lowering the condensation temperature of the purge gas over time.

In another embodiment, the present method comprises supplying a purge gas comprising steam and hydrogen to the steam reformer, and reducing the pressure in the reformer. And in another embodiment of the present fuel processing system, the system further comprises a vacuum pump for reducing the pressure within the reformer. As the  
5 pressure in the reformer (and, optionally, other fuel processing components) decreases, the boiling point of water decreases, thereby decreasing the condensation temperature of the purge gas. For example, at a system pressure of 25 kPa, the condensation temperature of steam would be 65 °C, and at a system pressure of 10 kPa, the condensation temperature of steam would decrease further to 46 °C. If desired, a dry inert gas, such as nitrogen, may be  
10 added to the purge gas, in which case the condensation temperature of the purge gas would be further decreased. By reducing the pressure in the reformer, it may be possible to purge with steam and hydrogen while reducing or eliminating efforts to heat the catalyst bed and/or following with a nitrogen purge.

It is possible that other inert gases may also contain small amounts of  
15 oxygen as a contaminant. This presents a risk of oxidation of the nickel in steam reforming catalysts where such inert gases are used for purging. Thus, the present method may be employed in fuel processing systems that employ inert gases other than steam during purging. Non-limiting examples of suitable such inert gases include nitrogen, argon and carbon dioxide. In these circumstances, the amount of hydrogen to be added to the purge  
20 gas will depend on the concentration of oxygen. Persons skilled in the art can readily determine suitable concentrations of hydrogen to be added to the purge gas for a given application.

In an embodiment of the present fuel processing system, the means for supplying a purge gas to the reformer may supply an inert gas such as nitrogen, argon,  
25 carbon dioxide, and mixtures thereof. For example, a pressurized storage tank may be used to supply the purge gas. Alternatively, a downstream fuel processing component could supply an inert gas stream. For example, the fuel processing system could comprise a pressure swing adsorption unit (PSA). A PSA could generate a gas stream comprising nitrogen from air, for example, which could be supplied to the reformer during purging. As